NOAO Observing Proposal *Standard proposal* **Panel:** *For office use.*
Date: September 30, 2005 **Category:** Star Clusters

Speckle Interferometry of Massive and Cluster Stars

PI: Brian Mason **Status:** P **Affil.:** U.S. Naval Observatory
Astrometry, 3450 Massachusetts Avenue, NW, Washington, DC 20392-5420 USA
Email: bdm@usno.navy.mil Phone: (202) 762-1412 FAX: (202) 762-1516

CoI: William I. Hartkopf **Status:** P **Affil.:** U.S. Naval Observatory
CoI: Douglas R. Gies **Status:** P **Affil.:** Georgia State University
CoI: Todd J. Henry **Status:** P **Affil.:** Georgia State University
CoI: Andrei A. Tokovinin **Status:** P **Affil.:** Cerro Tololo Inter-American Observatory

Abstract of Scientific Justification *(will be made publicly available for accepted proposals)*:

Conducted on NOAO 4-m telescopes in 1994, the first speckle survey of O stars (Mason et al. 1998) had success far in excess of our expectations. In addition to the frequently cited multiplicity analysis, many of the new systems which were first resolved in this paper are of significant astrophysical importance. Now, some ten years after the original survey, we propose to re-investigate all systems analyzed before ($N = 195$). Improvements in detector technology will allow for the detection of companions missed before as well as systems which may have been closer than the resolution limit in 1994. We will also make a first high-resolution inspection of the additional O stars ($N = 108$) in the recent Galactic O Star Catalog of Maíz-Apellániz & Walborn (2004).

Further, we propose to investigate several additional samples of interesting objects, including 15 accessible Galactic WR stars from the speckle survey of Hartkopf et al. (1999), 16 massive, hot stars with separations which would indicate their applicability for mass determinations (for fully detached O stars masses are presently known for only twelve pairs), and 56 multiple stars for a study of their co-planarity statistics.

Summary of observing runs requested for this project

Run	Telescope	Instrument	No. Nights	Moon	Optimal months	Accept. months
1	CT-4m	VIS	5	bright	Mar - Apr	Feb - May
2						
3						
4						
5						
6						

Scheduling constraints and non-usable dates *(up to four lines)*.

Report Documentation Page

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Scientific Justification *Be sure to include overall significance to astronomy. For standard proposals limit text to one page with figures, captions and references on no more than two additional pages.*

Massive stars are not well defined in their multiplicity, mass and formation mechanism. Here we address all three issues. We made a speckle survey [5,8] in 1994 to investigate the multiplicity of the brightest O & WR stars. Ten years later (and armed with an improved detector) is an opportune time for followup and expanded observations, for reasons outlined below.

Any study of multiplicity relying on a single inspection must deal with a nagging problem; namely, reliability of the results. As [13] stated: “absence of binary evidence . . . is not necessarily evidence of absence.” Some systems observed prior may have been in phases of close separation, and hence were unresolved. As the separations we can detect correspond to periods of decades for massive stars, it is important to repeat the survey after a timespan of order a decade. Systems needing general re-investigation are also significant in number. For example, there are several cases where a triple is indicated by spectroscopy, but we have yet to resolve the wide system (e.g., δ Cir; see [6]). Many of the O2/3 stars placed on the HRD are claimed to be very massive because they are so bright, but sometimes it is because they have another companion [9,10]. Confirmation of massive binaries in the Orion Trapezium [11] is within the resolution limit of a 4m telescope and while confirmation is important, failing this at another wavelength can set limits on Δm, and hence object type. For systems with two measures a third will allow the motion to be recognized as either linear or non-linear (i.e., Keplerian), indicating whether the pair is optical or physical. This is extremely important, e.g., in the case of ι Ori where dynamical analysis [4] of this complex runaway system virtually requires that the speckle companion, discovered in [8] at $0''.11$ separation, be optical rather than physical. One measure of this system can confirm its true nature. **The proposed survey will make significant strides in revealing the true multiplicity fraction of O stars.**

The mass-luminosity relation on the main sequence is well determined for A, F & G stars, but the two ends (O/B & K/M) are not well defined. Recent models of massive star formation [1] predict “stars with greater masses ought to have a higher frequency of close companions, and that many close binaries ought to have wide companions.” We propose testing this on a larger sample of Galactic O stars [7], to examine the trend and the occurrence of astrometric companions. While the sample is not large, 10 of the 12 new pairs found in [8] were additional components of known multiple systems. For massive stars the number of “unaltered” masses is limited, as the periods of double-lined eclipsing binaries are short enough to allow Roche lobe overflow. Determining model-independent stellar masses requires binary stars, and their use as single star analogs requires no mass exchange. According to [13] this means periods in excess of 3000 days. Our list of stellar mass targets (N = 16) all have preliminary semi-major axes less than $1''.0$, so there is some expectation that orbit computation may be possible in the not too distant term, for example, 15 Mon [2,3] (see Figure 1). **By examining this additional set we anticipate discovery of 5 pairs for future mass determinations in addition to obtaining more observations of systems appropriate for future combined solutions.**

Relative orientation of orbits in triple stars offers an important diagnostic of their formation mechanisms. Recent study [12] shows that there is a loose correlation between the angular momentum vectors of the inner and outer sub-systems in multiple stars, and that this can be reproduced by simulations of dynamically decaying stellar groups. The available observational material is, however, very limited. It can be extended by additional speckle measures that will provide second-epoch data (hence the sense of motion) for newly discovered close pairs in known wide binaries. The 56 such visual multiples are included in the present proposal. A greater number of multiple stars with known sense of rotation will allow study of angular momentum correlation as a function of additional parameters, such as degree of hierarchy [12], mass, mass ratio, etc.

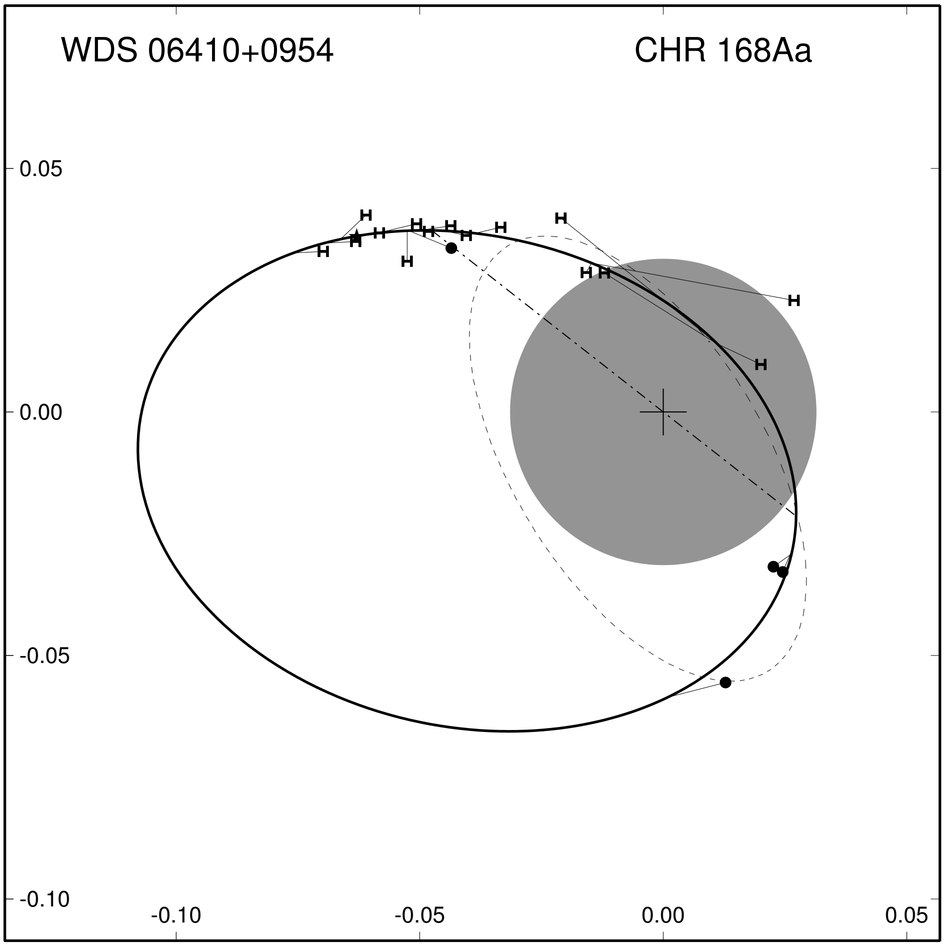

Figure 1: Preliminary orbit of 15 Mon, from data taken with the CHARA and USNO speckle cameras, the Navy Prototype Optical Interferometer, and HST. The NPOI measure is a filled circle. Speckle measures are filled circles (CHARA) or stars (USNO). HST-FGS measures are indicated by the letter **H**. The dot-dash line is the line of nodes, and the dotted ellipse is the orbit of [2]. The large shaded region represents the resolution limit of a 4-m telescope. HST measures were of noticeably lower quality in 1996-97 when FGS3 was in use. All later HST data were taken with FGS1r.

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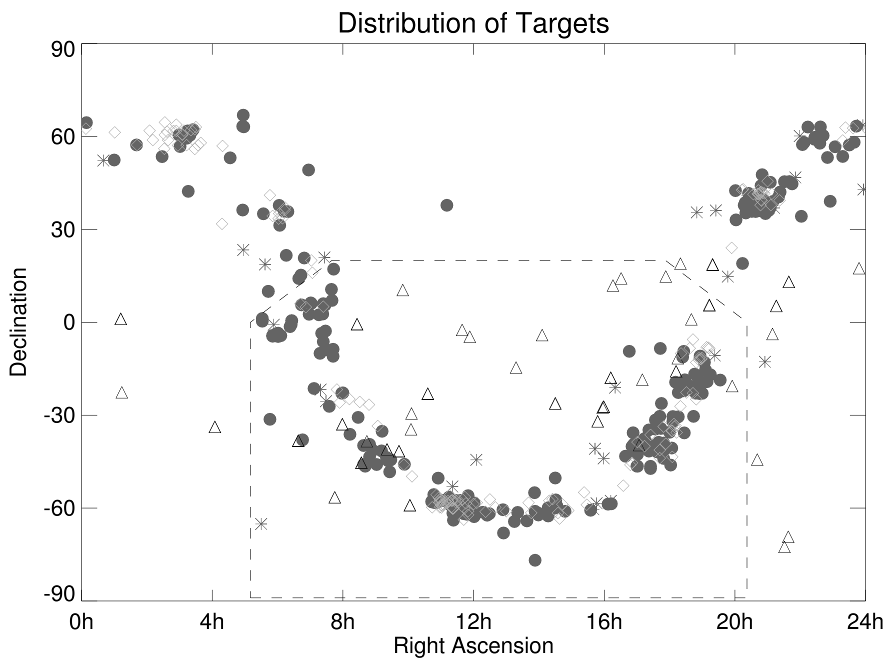

Figure 2: Distribution of targets in α-δ space. Circles are O or WR star from the 1994 sample. Diamonds are additional targets from the Maíz-Apellániz list. Asterisks are other hot, massive stars. Triangles are multiple stars. The region bounded by the dashed line indicates objects observable in the 25 March to 5 April window, and is defined by the times of evening and morning twilight on those dates.

Experimental Design *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science. (limit text to one page)*

Proprietary Period: *18 months*

Use of Other Facilities or Resources *(1) Describe how the proposed observations complement data from non-NOAO facilities. For each of these other facilities, indicate the nature of the observations (yours or those of others), and describe the importance of the observations proposed here in the context of the entire program. (2) Do you currently have an NSF grant that would provide resources to support the data processing, analysis, and publication of the observations proposed here?"*

The northern targets in Figure 2 are scheduled to be observed with the KPNO 4m telescope during 2005B (November 9-13, 2005).

Combined solutions (i.e., spectroscopy and astrometry) can yield a complete determination of stellar masses for double-lined spectroscopic binaries, or can allow for a more complete investigation of multiplicity by studying different period regimes (i.e., short period systems by spectroscopy and long period systems by astrometry). For multiple star systems the periods may range over several orders of magnitude, so the full analysis will include long-baseline optical interferometry results as well. Several systems first resolved by other observers and techniques can be confirmed here. Specific examples of these include HD 37742, first resolved by NPOI (Hummel et al. 2000, ApJ 540, 91) and HD 93129, first resolved by HST-FGS (Nelan et al. 2004, AJ 128, 323).

Previous Use of NOAO Facilities *List allocations of telescope time on facilities available through NOAO to the PI during the last 2 years for regular proposals, and at any time in the past for survey proposals (including participation of the PI as a Co-I on previous NOAO surveys), together with the current status of the data (cite publications where appropriate). Mark with an asterisk those allocations of time related to the current proposal. Please include original proposal semesters and ID numbers when available.*

Sixteen nights were allocated in 2001 for observation of approximately 3000 G dwarf stars to investigate the multiplicity relationship with age. The reduction is complete. Preliminary results were presented at a recent winter AAS meeting (2003, BAAS, 203, 4203). Final results are in preparation and will be submitted by the end of 2005.

Observing Run Details for Run 1: CT-4m/VIS

Technical Description *Describe the observations to be made during this observing run. Justify the specific telescope, the number of nights, the instrument, and the lunar phase. List objects, coordinates, and magnitudes (or surface brightness, if appropriate) in the Target Tables section below (required for WIYN-2hr, WIYN-SYN, YALO, and Gemini runs).*

For this observing program, we will use the USNO speckle camera, last mounted on the CTIO 4m in 2001. The camera has self-contained image correcting optics, microscope objectives, and interference filters. The optics head, along with the ICCD allowed us to observe doubles as faint as 15^{th} magnitude in 2001: well within the magnitude limit of the stars on this proposal.

The targets in this portion of our speckle program are in the southern sky. Depending on observing conditions, a typical observation — including both star acquisition and data collection — requires approximately 4-5 minutes. On an average night about 200 objects can be observed.

To adequately perform scale calibration and investigate errors in ρ-Δm space a total of 100 objects with a variety of separation and magnitude-difference combinations will be observed over the course of the run. As detection limits are strongly influenced by ambient conditions (seeing and transient clouds), approximately 80 objects will be observed per night to ensure that we are reaching the resolution limit at the desired magnitude difference, or if not, what those limits are.

Observation of all science targets would require five nights.

Instrument Configuration

Filters:	Slit:	Fiber cable:
Grating/grism:	Multislit:	Corrector:
Order:	λ_{start}:	Collimator:
Cross disperser:	λ_{end}:	Atmos. disp. corr.:

R.A. range of principal targets (hours): *5 to 20*

Dec. range of principal targets (degrees): *-80 to +20*

Special Instrument Requirements *Describe briefly any special or non-standard usage of instrumentation.*

Cabling of RG-59, and two nine-pin serial cables from the Cassegrain cage to the control room will be needed. We expect to arrive one day prior to the start of the observing run to verify cable trace and to correct any unforeseen problems.

We have two cables from our CTIO runs in 2001 (Cass cage and patch panel in control room) to facilitate ease of wiring up our equipment.

We will also be bringing our adaptor plate for the Cass mounting which was used last in Summer, 2001.